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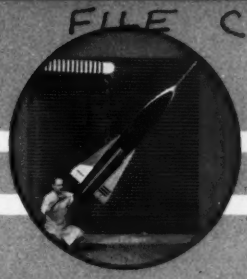


research trends

CORNELL AERONAUTICAL LABORATORY INC., BUFFALO 21, NEW YORK

Taking the Miss out of MISSILES

by RICHARD E. REINNAGEL

Reliability, Detail Design Must be Emphasized for Successful Guided Missile System

Recently the United States Army revealed that Cornell Aeronautical Laboratory had developed a new guided missile, the Lacrosse. The Army release described it as a surface-to-surface guided missile for close-support operation on the battlefield, and went on to say: "In development of Lacrosse emphasis has been placed on accuracy and mobility." The missile itself is only one part of the total weapon system, which includes a mobile launcher, a guidance station, and the necessary test and firing equipment. Test firings at White Sands Proving Ground during the past two years have been particularly successful.

The history of Lacrosse dates back to 1947, when the Marine Corps outlined a need for such a weapon. A feasibility study was conducted by the Applied Physics Laboratory of Johns Hopkins University, with this Laboratory's cooperation. In the course of the study, CAL saw several uncharted technical regions that would have to be explored for successful development of the missile system. Besides requirements for extremely precise distance and angle measurements, the equipment had to be lighter and more portable than equipment developed up to that point. The existence of these potential areas for original research played an important part in the Laboratory's decision to undertake the project.

In 1949, then, an active research and development program was initiated at CAL. Sponsorship passed from the Navy to Army Ordnance the following year. Notwithstanding the fact that Lacrosse progressed through the various stages of development rapidly and at a comparatively low cost, the actual lapsed time was nearly eight years. Millions of dollars were spent in demonstrating the feasibility of the system and in evolving a pre-production design which could be used as a basis for a complete tactical design by a production contractor. With this background in mind, and in view of the tremendous amount of design and test work which remains to be done by the production contractor, the Glenn L. Martin Company, we should ask ourselves this question:

Why is the evolution of a useful missile system such a gargantuan undertaking? Guided missiles and their associated control systems, after all, use the same physical principles, materials, and components as commercial aircraft. Why then, has the task of developing missile systems on a national basis taken many times the engineering manhours required to develop conventional aircraft? A significant part of the answer can easily be stated. In all the complex electromechanical systems

"In development of Lacrosse emphasis has been placed on accuracy and mobility."

A missile should be handled as any piece of ammunition, yielding the same reliable performance expected of a 105 mm shell.

which are a part of our daily life, and in those which form the backbone of military operations, human intelligence can be used to make corrections, replacements, or equipment adjustments while the system is in operation. In any guided missile, be it Lacrosse, Nike, or another, the success or failure of the mission depends upon how well the unattended system can function in an environment entirely different from that under which it was set up and adjusted. For this reason guided missile systems have required an unprecedented amount of detail design, and have demanded that a philosophy of built-in reliability stand behind every technical decision and every component choice.

Through our own Lacrosse experience we have acquired real respect for the magnitude of the problem and have strongly emphasized the importance of attention to the minutest detail. Full attention to detail design of a system cannot be delayed until the system is ready for actual hardware design and contruction. Detail design considerations will influence the basic block diagram of the system, as well as the system selection itself.

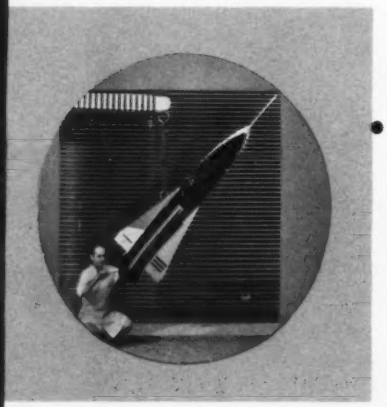
Selection of the System

Any guided missile system is designed to meet a well-defined military requirement — one which exists within the framework of existing or postulated military requirements. Flexibility of the system and its adaptability to changing military situations are primary considerations in selecting it to solve a military problem. These needs are particularly important because of the large time-span between the inception of a design and delivery of field-tested equipment to combat troops. During this time-span the designer must constantly guard against obsolescence. To be of maximum use, the guided missile system must accommodate new military tactics which may evolve during the development stage. The system must support other new systems, so as to complement rather than restrict total military usefulness. To meet these objectives, the detail designer must contribute to selection of the system and must constantly be aware of changing military tactics and use.

Design Objectives

The guided missile system must have the broad objectives of fulfilling tactical requirements with equipment which is militarily useful. A system which meets tactical requirements for range, accuracy, and fire power must also meet requirements of operational simplicity, cost, maintenance, and reliability. The designer must account for these requirements when he is selecting the basic block diagram for the system.

The overall design which is finally selected for development should not have too many design and development difficulties in its technical areas. Detail requirements of each sub-system should be thoroughly considered so that impractical requirements will not be made in one area to ease the design burden in another. For example, an aerodynamically unstable



THE COVER

Unlike Lacrosse, not all the Laboratory's weapon system programs are carried through the late development stages. In some cases the goal is simply to establish feasibility, leaving the development task to others.

The bomber defense missile (BDM) pictured here was an outstanding example of this approach. In a recent project for the Air Force, CAL studied the firing of such missiles from high-speed aircraft. Many unusual problems were introduced by the requirement for rearward launching. A background of engineering knowledge in missile aerodynamics and controls, plus a readily available high-speed wind tunnel, enabled CAL to pursue the problem effectively.

A new system for controlling a missile from a fast-moving aircraft was subsequently conceived and developed by the Laboratory. Next, the system's feasibility was successfully demonstrated in test firings from a rocket-propelled sled at Holloman Air Force Base. When the Air Force then turned the project over to industry for development, the Laboratory was retained to provide engineering assistance.

missile airframe configuration may yield the best missile design but result in an unjustifiably complicated control loop.

New guided missile systems are usually overburdened with refinements which the designer considers necessary for system perfection. Early in the design phase of the system, the detail design of the entire system and sub-system must be simplified, reduced to basic elements and re-evaluated. If the system cannot operate within design objectives when it is simplified, it may be beter to abandon it and to adopt another. A great danger exists in becoming committed to an impractical system due to schedule pressure.

Utilization of the System

After a system is devised which is simple and still able to meet performance requirements, it must be reexamined for tactical applications. Any system composed of many unique and highly complex sub-systems may be impractical to operate and maintain when it is being used in the field. In most cases, the designer cannot wait until the system has been reduced to "field test hardware" to determine its practicability. The designer must fully consider this aspect of the design as soon as prototype models are available.

To illustrate this point, consider the missile as a sub-system of a guided missile system. Ideally, from the tactical point of view, the missile should be handled as any piece of ammunition. It should not require special handling, testing, or storage. Combat troops have a right to expect the same reliable performance from this projectile as they do from a 105 mm shell. Most important, it should not be necessary to test each missile at every storage depot before shipping it forward. The missile should be so designed, fabricated, and crated as to obviate the need for any tests from time of manufacture to time of use.

To date, few, if any, missile programs have achieved enough reliability to eliminate extensive testing between the time of manufacture and actual firing. Unfortunately, personnel working on guided missiles accept testing and repair as normal procedures. They have rationalized the situation on the basis of the complexity and toughness of the job. In the past few years, development and use of test equipment have been emphasized in an effort to improve the reliability of missile flights. This may do some good, but the basic difficulty still arises from the detail design. No amount of testing will change the inherent reliability of the system. Reliable missile systems can be produced, just as reliable automobiles, refrigerators, and public communication systems have been produced.

In the commercial field we expect consistent and reliable operation, combined with excellent performance at a competitive price — and we get it. In the missile field there is a tendency to justify any amount of "special care" if some small measure of success can be achieved. There is too much concern over the success of a flight and too little concern over the subsystem failures, the large numbers of field tests, and the rework necessary for this measure of success. In most cases, the best **long-term** interests of the missile program would be served by eliminating field maintenance or rework and returning all defective missiles or missile components to the manufacturer for correction.

Need for Detail Design

It is relatively easy to draw a major block diagram for a physical system which will accomplish a given task. But unless designers of major block diagrams have a comprehensive appreciation for the practical performance limits of each of the blocks, the resultant system will be either impossible to develop or excessively troublesome in one or more areas. Practical block diagrams for sub-systems within each block of the major diagram are the most difficult to generate and, therefore, demand the most detailed attention. Success or failure of the system is determined by the skill of the designer of these units, and, in the aggregate, by the detail design of the entire system.

Experience and mature judgment — important ingredients in establishing the detail design of each component or circuit of a missile system.

Detail design of military equipment must be made compatible with the tactical environment under which the equipment must operate. Experienced designers of military equipment have a good understanding of this environment. An equally important consideration for them, however, is the storage and handling environment. Design requirements for these conditions can be defined only in the broadest terms. Such items as the magnitude and duration of shock and vibration, extremes of temperature and humidity, or wearout through inspection and test, complicate the design problem and may actually dictate the detail design. Because the duration of storage and handling conditions

In the field, missiles may undergo extremes of shock, vibration, acceleration, and temperature simultaneously.

of the missile are uncertain, detail designers must be extremely conservative about the use of new components or techniques which have not been fully qualified. On the other hand, too much conservatism is technological stagnation. Experience and mature judgment are probably the most important ingredients in establishing the detail design of each component or circuit of the system.

The largest contributing factor to failure of a system at all stages in its life cycle is poor detail design. The broad aspects of overall system design are under continuous and high level scrutiny, and, if properly implemented, they will be satisfactory for the mission. Detail design is too often delegated to juniors who, through lack of experience, simply cannot provide for all of the factors involved when designing a piece of equipment to be used under severe operating conditions.

Every part of the system must be designed with extreme care and full regard for the limiting characteristics of each component in its particular application.

It is not enough for a component to meet the requirements of the appropriate general specification. It must also be approved by the designer for each application. The experienced designer can have no mental reservations as to the adequacy of the design. Each item must pass an intelligent and realistic set of environmental tests. These tests, however, will never be all-inclusive or represent actual conditions of use. For example, in actual use, shock, vibration, acceleration, and temperature extremes can occur simultaneously. In testing operations, these environments are applied serially. Often a part is destroyed in one of these tests because of the duration of the test or because it has been used previously in other environmental tests. When a replacement part is entered into the environmental test cycle, how are the results to be interpreted from the standpoint of the actual requirements of use? When a part, component or assembly has passed all of the tests, it must also pass the critical judgment of the designer.

The design should be thoroughly integrated and standardized. In a missile system, where all elements are in series (that is, if one element fails, the entire system fails), the series elements should be few in number and should have maximum reliability. Integration of this type can be best achieved if the total system design is the responsibility of one engineer. If responsibility is broken down to servo, guidance, RF elements, and others, integration becomes difficult if not impossible.

Importance of Reliability

Reliability must be one of the primary considerations of every design engineer — a consideration which he cannot delegate. He must design reliability into the system from its very inception. While he may take advantage of numerous administrative devices to keep abreast of the "state of the art" and to assist him in this phase of his work, his responsibility for designing a reliable system remains undiluted.

The overall reliability of a particular system can best be evaluated by designers fully experienced in the field. With this in mind, designers may find it advantageous to submit system designs to other experienced men within the organization for review. By this technique, design concepts, as well as implementation of the design, can be effectively reviewed.

Basically, good reliable components are lacking. Many good systems exist on paper, but in actuality they fall short of the mark because of component failure — the gyro drifted or the relay failed. Perhaps the approach is wrong — along with a continuous search for new and better guided missile systems, it is imperative that we continue to emphasize development of better components. To use standard components, tests to establish their workability in flight must be developed. For improved reliability, more emphasis should be placed on limit testing to indicate the margin of safety in the component; then perhaps less emphasis can be placed upon operational testing, which only indicates how well the item is working during the test and under the test environment.

The Future

In a broad sense, guided missiles will not, and cannot, be employed to their full military potential as long as they are held to be merely the erratic or eccentric children of the scientist. A practical goal is to eliminate the costly and militarily unsatisfactory practices of front-line testing, calibration and repair, and thus increase the confidence of the user in these devices. Through continued and unrelenting emphasis on the detail design and a real demand by producers as well as users for unconditional reliability, we can produce totally useful guided missile weapon systems.

REPORTS

Reports issued on CAL's guided missile work are classified and cannot be listed for distribution.

BOMB RUN

In a Wind Tunnel

by WILBERT SCHWARTZAPFEL

Maintaining Bombing Accuracy with New High-Speed Aircraft

FIG. 1 — F-86 with underwing model of 750-pound general purpose bomb.

The large speed advantage of modern bomber aircraft over their World War II predecessors is a major factor in degrading the accuracy of bomb delivery, the bomber's prime function. The changes in aircraft shape at the bomb-carrying locations, whether those locations are internal bomb bays or external wing mounts, cause distorted flow patterns and result in aerodynamic interference forces. As the operational speeds of aircraft increase, these interference forces increase to the point where they become large relative to the bomb mass and inertia. As a result, large accelerations take place when the bombs are released in their bomb run. In many cases bombs pitch, yaw, spin, and tumble end over end after release. A bomb has even been known to return to its bomb bay. Besides the obvious hazard to aircraft and crew, bombing accuracy is seriously impaired.

Since the aerodynamic forces in all directions increase during these oscillations, extra offset and longitudinal displacements result, with a degradation of accuracy and possibly a missed target. In terms of the Mach number, the magnitude of the aerodynamic forces increases as its square, for a particular altitude. In many cases an even more important effect is the change in the airflow pattern as the Mach number varies. This is usually characterized by high turbulence and buffeting for airflows within internal bomb bays. For the case where the bombs are hung below the wings, the changes with Mach number are noted as non-uniform flow with the associated large upsetting bomb loads and the possibility of contributing to flutter. For those aircraft which have poor airflow characteristics, it could mean restrictions on bomb bay opening speed, bomb release speed, maximum speed, or a combination of all these.

Cornell Aeronautical Laboratory's investigation of the bomb-airplane separation phenomena is one phase of the Air Force's long-term program on bombing problems. Since 1947 the Laboratory has been continuously active in investigations of bomb carriage, packaging, separation, and stabilization. One of the results has been a successful development of a parachute ejection and stabilization system.

Wind Tunnel Technique

In 1952 a program was established to develop a wind tunnel technique to simulate free-flight bomb-separation conditions. This initial program was established to simulate high subsonic releases from an internal bomb bay. A B-47 aircraft model was selected so that free-flight data would be available for comparison. A subsequent program covered underwing store releases from an F-86 aircraft (Fig. 1).

The long delays now encountered in solving the bomb release problem for new aircraft have emphasized the desirability of establishing a simulation technique for aircraft bombing. Obtaining bomb release data before prototype testing begins can materially advance the airplane's operational date. In this respect, the wind tunnel offers many significant benefits that enhance its use as a design tool. These include the lack of risk to operating personnel, quick configuration changes, relatively low costs and the large number of tests possible each hour.

The wind tunnel technique used is that of dynamic simulation of the initial bomb trajectory through free drops of scale model bombs. Model bombs are released from the model aircraft and fall freely to the tunnel floor. In this case the model bomb release duplicates a full-scale release by integrating the accelerations imposed on the bomb by the aerodynamic forces, thus establishing its trajectory. Only that portion of the bomb trajectory within the disturbed air region in the immediate vicinity of the aircraft is of interest; the remainder of the trajectory in the undisturbed air is easily established.

Mach Number Simulation

Until recently free bomb drops in the tunnel to obtain dynamic similiarity have had only a limited application in programs of government research organizations and aircraft manufacturers. In these cases, however, no attempt has been made to simulate the full-scale Mach number. Since it is in high-speed flight that adverse bombing conditions are noted, the Mach number effect appears significant. The CAL tunnel technique is to test the model at the full-scale Mach number.

By simulating Mach number, true dynamic similarity between model and full-scale in a free drop is prohibited, simply because it is impossible to scale correctly the body forces and the damping forces on the bomb simultaneously. Body forces, such as lift and drag, are directly responsible for establishing the trajectory, while damping forces reflect the rate of decay of any oscillations. A closer approximation to the correct scaling for both of these can be achieved through a technique of ejecting a light bomb at a relatively high velocity. In this case the high vertical ejection velocity overcomes the normal gravity drop to compensate for the scaled accelerations in the other directions. Even in a free drop, the body forces are only approximated because of an angle-of-attack error introduced by the vertical velocity of the bomb being incorrect through the inability to scale gravity. The effect of the incorrect damping forces is small during the initial portion of the bomb trajectory, since the free fall bombs will oscillate only about one full cycle and the resultant error is hardly noticeable in so short a period.

Similarity criteria require that the static air pressure within the tunnel be reduced in order to scale the body forces correctly in a free drop when simulating full-scale Mach number. This makes it mandatory that a variable density wind tunnel be used. The relationship between full-scale and model conditions is such that when the tunnel pressure ratio equals the model scale the test is simulating a free flight drop. This relationship holds true for a model bomb density equal to that of the full-scale bomb. One example would be a test with a 1/6-scale airplane model at a tunnel static pressure of 1/6 atmosphere. A 1/6-scale model is rather large for a bomber aircraft, but smaller scale models will require tunnel static pressures correspondingly lower than 1/6 atmosphere.

In order to investigate what happens when bombing at altitude, the tunnel pressure must be reduced even further, or conversely, the bomb mass and inertia can be increased. Since obtaining a pressure of 1/6 atmosphere in a tunnel is difficult and, even in a tunnel such as the CAL 8-Foot Transonic Wind Tunnel, requires about two hours of pumping time, no further reduction in tunnel pressure is deemed feasible. This, then, poses the problem of devising, fabricating, and testing as heavy a model bomb as possible and of varying the simulated altitude by means of the easily controlled tunnel static pressure.

A closely associated problem was that of preventing damage to the tunnel from these heavy bombs. At high test speeds with large scale models a screen or net to catch the bombs would absorb too much tunnel power, but would be satisfactory at low testing speeds or with small scale models. To solve this problem CAL developed a bomb that would break up and move harmlessly around the tunnel. This frangible bomb consists of a thin case, strong enough to support the heavy bomb filler, yet brittle enough to shatter into many small pieces upon impact. The filler has to be as heavy as possible, non-toxic, non-corrosive, and easily handled. The case material finally selected is polystyrene with certain additives, while the filler is powdered red lead with an oil binder. About 10% by weight of SAE 10W oil liquefies the filler to a satisfactory pouring consistency with a specific gravity of 4.7 for the mix. In assembly, the several molded part of the case are glued together and the bomb filled through a hole at the nose which is then plugged and sealed.

Instrumentation

During the tunnel tests two independent camera setups provide a record of the bomb trajectories in the tunnel. (Fig. 2) These permit either stroboscopic or motion picture records to be taken during each run. The stroboscopic pictures permit trajectory analysis, while the motion pictures show the bombs dropping before they emerge from the bomb bay. For the stroboscopic pictures three still cameras are mounted outside the tunnel in a horizontal plane below the aircraft model. These are aimed through windows in the wall of the test section, so that the attitude and bomb position can be triangulated from any two of the cameras. A known grid is photographed beforehand to provide a frame of reference. A multi-exposure record of a bomb drop is shown in Fig. 3.

A drop record is provided immediately after each stroboscopic run by a Polaroid Land Camera. Two movie cameras are also installed to view the model bomb bay from the fore and aft bomb bay walls so that they record the first moments of bomb release. A

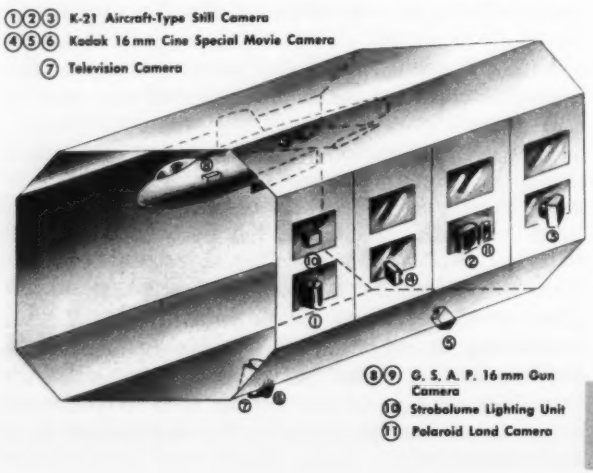

①②③ K-21 Aircraft-Type Still Camera
④⑤⑥ Kodak 16 mm Cine Special Movie Camera
⑦ Television Camera
⑧⑨ G. S. A. F. 16 mm Gun Camera
⑩ Strobolume Lighting Unit
⑪ Polaroid Land Camera

FIG. 2 — Wind tunnel camera installation, showing B-47 model used for bomb bay tests.

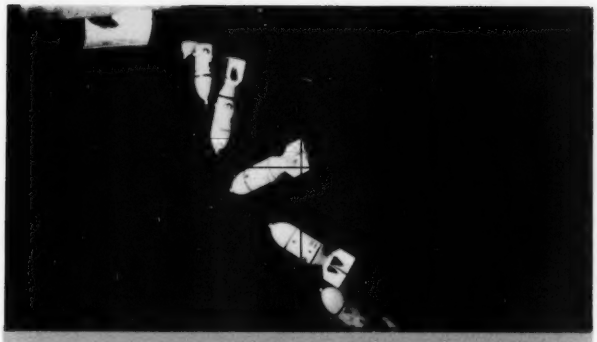


FIG. 3 — Stroboscopic photo of 1000-pound general purpose box tail bomb in drop from bomb bay.

television camera provides a view of conditions in the tunnel before each run or bomb drop.

CAL's programs ultimately explored aircraft bombing characteristics both from the internal bomb bays common to large bomber aircraft and from the underwing positions typical of smaller fighter and fighter-bomber types. That the program did actually provide true simulation of full-scale bomb drops was satisfactorily shown for a series of drops over a spread of flight conditions up to Mach number 0.9 for both internal and external releases. These drop test data also confirmed theoretical airflow and trajectory computations.

Other studies with an internal bomb bay configuration established the effects of bomb position within the bomb bay. Such devices as flaps, spoilers, and flow deflectors were installed on the aircraft model to modify the airflow around the bomb bay, thus improving the bomb separation characteristics. The effects of bomb position were also investigated for various locations underneath the aircraft wing. In addition, idealized positions for underwing bombs were investigated through an airflow analysis.

The latest series of tests has extended the free drop technique to the supersonic regime. Investigations included bomb releases from both internal and external locations at supersonic speeds. However, it will still be some time before any comparative data from full-scale tests become available. Other planned explorations at supersonic velocities involve theoretical and experimental airflow interference studies about bomb bays and externally carried bombs to add still more information to our storehouse of knowledge and to improve still further our aircraft bombing capabilities.

REPORTS

Reports presenting specific test data and details of the test program are classified and cannot be listed. An unclassified report touching on this work is:

"Similarity Laws for Dynamic Model Testing," Deitchman, Seymour J.; CAL Report GC-910-C-14; September 1956.

ABOUT THE AUTHORS

WILBERT SCHWARTZAPFEL, head of the missile systems section of the Systems Research Department, is professionally — and personally — enthusiastic over weapons systems analysis in the field of operations research. For the past five years Mr. Schwartzapfel has evaluated ballistic missile systems and surface-to-air missile systems, as well as all manner of aircraft and missiles that make up the offensive weapons of the Tactical Air Force.

Mr. Schwartzapfel joined CAL in 1947, in what was then the Special Projects Group. His early work was mainly in engineering research, with applications in aerodynamics, structures, and mechanisms. This research included work on missile launching systems, the aerodynamic effects of battle damage, and studies of high-speed bombing problems.

After graduation from New York University in 1940 with a BAeE degree he worked for the Brewster Aeronautical Corp. in structural and layout design of major aircraft components. During World War II he spent one year with the Air Force as an engineering aide at the Wright Air Development Center. From 1945-1947 he was an assistant project engineer for the Stratos Corp. in the design and development of aircraft cabin air conditioning and pressurization equipment.

Mr. Schwartzapfel has an MS degree from the University of Buffalo, and is a member of the Institute of Aeronautical Sciences.

RICHARD E. REINNAGEL, Lacrosse project engineer, has taken part in almost every phase of CAL's weapon system development for the Army, from original studies in 1947 with the Johns Hopkins University, to the current transfer of technical responsibility to the Glenn L. Martin Company, producers of the surface-to-surface missile. Administratively, Mr. Reinnagle has implemented design decisions of CAL's technical departments; technically, he has made major contributions in the weapon's airborne electronics.

He joined CAL in 1946 as a research engineer in the Physics Department. He was made administrative coordinator in June, 1951, transferred to the engineering design section of Development Division in 1952, and last year was made head of the airborne electronics section of Weapon Systems Design.

During these years, Mr. Reinnagel has also worked on the electronic design of a bomber defense missile, on three-dimensional presentations of a multiplicity of radar targets, and on research on a free-fall test vehicle.

He was employed for a short time in General Electric's junior engineer training program, and from 1941 to 1946 at USAF's Watson Laboratory at Redbank, N. J. In the early stages of World War II he assisted in developing communication equipment for use by the Army Air Force, and from 1944 to 1946, he studied anomalies in upper atmospheric propagation.

Mr. Reinnagel has a BSEE from Syracuse University. He is a licensed professional engineer, and member of the IRE.

RECENT C. A. L. PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"CORRELATION STUDIES OF LINEAR AND NONLINEAR SYSTEMS," Rideout, V. C. and Spooner, M. G.; based on a thesis presented to the faculty of the University of Wisconsin; Oct. 1956; 25 pages.

An introduction to the use of the generalized error function in the evaluation of such systems as filters, amplifiers, servomechanisms, etc.

"REFLECTION OF AN ELECTROMAGNETIC PLANE WAVE FROM A SURFACE WITH SMALL ROUGHNESS," Biot, M. A.; CAL Report BE-745-T-129; Mar. 1955; 40 pages.

In addition to revealing limitations of approximate methods, the present exact solution reveals a phase reversal of the reflected wave.

"INVESTIGATION OF THE COMPRESSIVE, BEARING, AND SHEAR CREEP-RUPTURE PROPERTIES OF AIRCRAFT STRUCTURAL METALS AND JOINTS AT ELEVATED TEMPERATURES," Vawter, F. J.; Guarnieri, G. J.; Yerkovich, L. A.; Derick, G.; CAL Report KB-831-M-21 (WADC TR 54-270, Part 2); Aug. 1955; 86 pages.

The results of the second year's work are summarized in this report.

"EFFECTS OF OVERHEATING AND OVERSTRESSING OF METALS," Yerkovich, L. A.; CAL Report KH-722-M-6; Apr. 1952; 59 pages.

A study of the overloading and overheating effects on the creep and fracture properties of alloys suitable for jet engine service. Design charts are presented.

"THE FLUTTER CHARACTERISTICS OF LOW ASPECT RATIO WINGS IN INCOMPRESSIBLE FLOW — DEVELOPMENT OF THE BASIC THEORY OF THE METHOD," Lawrence, H. R. and Stone, H. N.; CAL Report SB-859-A-1 (WADC TR 54-412); Oct. 1954; 27 pages.

The method of determining the aerodynamic characteristics of low aspect ratio wings oscillating in an incompressible flow is combined with the equations of motion of a vibrating wing to produce a relatively simple flutter analysis procedure.

"A THEORETICAL ANALYSIS OF THE VISCOUS FLOW IN A NARROWLY SPACED RADIAL DIFFUSER," Woolard, H. W.; paper presented at the annual meeting of the American Society of Mechanical Engineers, New York; Nov. 1956; 7 pages.

A theoretical method is developed for calculating the radial pressure distribution for laminar viscous flow in a narrowly spaced radial diffuser having arbitrarily shaped walls deviating only moderately from a plane surface.

"BOUNDARY CONDITIONS IN NONSTEADY FLOW," Rudinger, G.; paper presented at the 9th International Congress of Applied Mechanics, Brussels; Sept. 1956; 14 pages.

Problems involving quasi-one-dimensional nonsteady flow in duct require the knowledge of the conditions that govern the reflection of pressure waves from various flow boundaries. A brief review of the present knowledge in this field.

"TAKING THE HEAT OFF MINIATURE EQUIPMENT," Welsh, J. P.; reprinted from *Electronics*, Oct. 1956; 6 pages.

Brute-force methods of reliable operation dependent upon high-temperature electronic components are now giving way to establishment of low-temperature-gradient paths, maintained by adequate heat transfer and effective heat sinks.

"A FULL RANGE LONGITUDINAL AND LATERAL AIRSPEED INDICATOR FOR HELICOPTERS," Spaulding, E. R. and Skelly, E. T.; paper presented at the Joint Conference of the Office of Naval Research and the Bureau of Aeronautics, Washington, D.C.; Oct. 1955; 19 pages.

This paper describes an airspeed indicator based in principle on the measurement of the difference in the tip speed of one rotor blade relative to the air as the blade rotates about its hub.

"PRECISION PHOTOMULTIPLIER GAIN STABILIZATION," Hendrick, Roy W.; reprinted from *The Review of Scientific Instruments;* Apr. 1956; 1 page.

The circuit described is capable of providing a portable and precise photomultiplier with its required stability for voltage fluctuations in excess of 30%.

"THE APPLICATION OF THE SHOCK TUBE TO THE STUDY OF THE PROBLEMS OF HYPERSONIC FLIGHT," Hertzberg, A.; reprinted from *Jet Propulsion;* July 1956; 7 pages.

This paper discusses some of the new scientific and technical problems introduced by the high temperature conditions encountered in hypersonic flight.

"BALLISTIC MISSILE PERFORMANCE." Reece, J. W.; Joseph, R. D.; Shaffer, D.; reprinted from *Jet Propulsion,* Apr. 1956; 5 pages.

A semianalytic method is derived for calculating the range of one-stage, ballistic, rocket propelled, surface-to-surface missiles.

"THE IN-FLIGHT COLLISION PROBLEM," Brantley, J. Q.; reprinted from the *Aeronautical Engineering Review,* July 1956; 9 pages.

A discussion of cooperative collision warning and prevention vs, self-sufficient (or air-borne radar) systems.

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